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Improving the Quality of Freeze Dried Rice: Initial Evaluations

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ABSTRACT

The focus of the work reported here is to evaluate a selection of readily available rices to determine cooking, freeze drying and rehydration characteristics, with the aim of improving the quality of freeze dried rice used in Australian military ration packs. Samples were examined by sensory evaluation, texture profile analysis and environmental scanning electron microscopy. The findings of this study will provide guidance for an expanded series of production scale improvements and evaluations.

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Improving the Quality of Freeze Dried Rice: Initial Evaluations

Executive Summary

Rice (*Oryza sativa*) is one of the world's most important staple crops, most commonly sold as a ready-to-cook, milled grain. Freeze dried (FD) rice is a form of instant rice with a very low moisture content, making it an especially light-weight, long shelf life food product. It is used in Australian military combat ration packs (CRP) and has been manufactured in our production facility for approximately 40 years.

The purpose of this project is to improve the quality of FD rice produced for use in CRP. The focus of the work reported here, is to evaluate a selection of readily available rices to determine cooking, freeze drying and rehydration characteristics, within the context of the DSTO-Scottsdale production facility. These preliminary activities will provide guidance for an expanded series of production scale improvements. The activities were structured in two parts:

- Part one, laboratory scale evaluation of five rice types (Jasmine, Basmati, Brown, Calrose and Parboiled rices) to determine suitable cooking, drying and rehydration parameters.
- Part two, production scale evaluation of the rice types giving favourable results in part one.

Samples of the in-house manufactured FD rice (controls) and commercially available FD rice were also evaluated.

Rice cooked using the rice cooker, absorption method was superior in flavour, texture and physical integrity compared to rice cooked using the excess boiling water method. Jasmine and Basmati rices cooked by rice cooker were sticky and difficult to spread on freeze dryer trays. Parboiled rice cooked by rice cooker was easily spread on the trays.

Rehydrated FD Jasmine, Basmati and Parboiled rices—cooked by rice cooker prior to freeze drying—were superior to rehydrated controls and the commercial product. The most significant problems with the latter rices were bursting and breakage of grains and mushy, chalky, grainy textures with poor, bland flavours. Parboiled rice retained its integrity and appearance better than Jasmine and Basmati rices, although Basmati was less gritty than Parboiled and Jasmine.

The findings of this study will provide guidance for Phase 2, in which an expanded series of production scale improvements will be conducted and evaluated.

Conclusions

It is concluded that:

- there is scope to refine in-house processing conditions to improve final product quality
- rice cooked by an absorption method and freeze dried is of better quality than rice cooked in excess boiling water prior to freeze drying
- sensory and physical characteristics of FD rice depend on the rice type, processing method and freeze drying conditions, although the precise relationships have not been determined.

Environmental scanning electron microscopy imaging was found to be useful for examination of FD rices. It indicated that:

- case hardening of FD rice grains may be linked to freeze drying conditions
- internal structures of the rices are more open and porous following cooking and freeze drying, however there may be an upper limit to pore size beyond which quality is sacrificed.

An improved understanding of the relationships among processing conditions, structure, physical characteristics, rehydration behaviour and sensory quality would facilitate efforts to improve the quality of FD rice.

Recommendations

- Develop improved knowledge of the structure of FD rice and textural parameters to inform refinements to processing conditions, including:
    - investigating the suitability of small angle X-ray scattering and focussed ion beam scanning electron microscopy to examine internal structures
    - quantifying porosity and density
    - investigating the cause and importance of case hardening as a factor affecting the quality of FD rice
    - identifying links between structure and breakage susceptibility, rehydration behaviour and sensory quality.
- Review current in-house rice cooking practices, including cooking time, frequency of stirring and number of rinses.
- At a production scale, investigate the feasibility of cooking rice by an absorption method prior to freeze drying.

Contents

Glossary

COTS	Commercial-off-the-shelf
CRP	Combat ration pack
DSTO	Defence Science and Technology Organisation
ESEM	Environmental scanning electron microscopy
FD	Freeze dried
TPA	Texture profile analysis
W:R	Water to rice ratio

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1. Introduction

Rice (*Oryza sativa*) is one of the world's great staples, with total production of milled rice estimated at 494 million tonnes for 2014/15 [1]. Quality varies greatly among rice cultivars and growing regions, as well as being subject to cultural preferences for different cooking techniques and final characteristics. The people of India, Bangladesh, Nepal, Sri Lanka, Pakistan, Burma and Thailand generally prefer a cooked rice texture which is somewhat hard, discrete and fluffy. By way of contrast, most people in Japan and Korea prefer rice with a soft, sticky and lumpy texture. In Indonesia, the Philippines, Malaysia, Vietnam, Laos and Cambodia, rice with intermediate characteristics usually has the highest acceptability. [2]. There is no single method of cooking rice that can be applied successfully to all varieties.

Rice is most commonly sold as a ready-to-cook, milled grain. Increasingly, it is available as a heat-and-serve product in a flexible retort pouch, and as instant rice that can be prepared quickly by the addition of hot water. Freeze dried (FD) rice is a form of instant rice with a very low moisture content, making it an especially light-weight, long shelf life food product suitable for use in military ration packs, known in Australia as combat ration packs (CRP). FD rice is used in 25–30% of individual, 24-hour Australian Defence Force CRP and has been manufactured in the DSTO-Scottsdale production facility for approximately 40 years.

The work reported here is the first phase in what is expected to be a series of activities to improve the quality of FD rice produced for use in CRP. Improvement themes are product texture following rehydration, alternatives to plain FD rice, and fortification with vitamins and minerals. Phase 1, the focus of this report, is to evaluate a selection of readily available rices to determine cooking, freeze drying and rehydration characteristics, within the context of the DSTO-Scottsdale production facility. These preliminary activities will provide guidance for Phase 2, in which an expanded series of production scale improvements will be conducted and evaluated.

2. Project Plan

2.1. Structure

Phase 1 was structured in two parts:

- Part one, laboratory scale evaluation of five rice types to determine suitable cooking, drying and rehydration parameters.
- Part two, production scale evaluation of the rice types giving favourable results in part one.

2.2. Part one, laboratory scale evaluation

A laboratory scale trial was set up to compare and evaluate five types of rice that may be suitable for freeze drying. The rices were cooked using two methods—stove top using excess water and rice cooker using the absorption method—and dried in a laboratory freeze dryer. Rehydration time and temperature conditions were evaluated. Analyses were performed on

the rehydrated rice samples to determine moisture content, texture and basic sensory characteristics.

Samples of a commercial-off-the-shelf (COTS) FD rice and the in-house manufactured cooked and FD rice were also evaluated.

2.3. Part two, production scale evaluation

A production scale trial was conducted on a subset of the rices used in part one (Table 1). They were cooked using commercial kitchen rice cookers and then freeze dried using a production scale freeze dryer. Samples of the in-house manufactured FD rice were also obtained for evaluation. Freshly cooked and rehydrated freeze dried rice samples were analysed to determine texture and moisture. Environmental scanning electron microscopy (ESEM) analyses were performed on FD rice samples. Table 1 summarises the activities of both parts of the project.

Table 1. Outline of parts one and two: sample treatments and analyses

Part	Samples	Cooking methods	Freeze drying	Analyses
Part one, Laboratory scale	Jasmine Basmati Brown Calrose Parboiled	Stove top & domestic rice cooker	Laboratory freeze drier	Texture Moisture
	Jasmine Basmati Parboiled	Commercial rice cooker	Laboratory freeze drier	Sensory evaluation
Part two, Production scale	Jasmine Basmati Parboiled	Commercial rice cooker & steam-jacketed kettle	Production freeze drier	Texture Moisture ESEM Sensory evaluation

3. Materials and methods

3.1. Materials

Samples of four types of rice were purchased from a local supermarket: Jasmine; Basmati; Brown medium grain; and Calrose medium grain rice (all SunRice products). A fifth rice, SunRice Parboiled long grain, was obtained from a wholesaler as an addition to the regular supply for DSTO's manufacturing facility. All samples were within their best-before dates by 12–18 months and were stored for approximately two weeks in a temperature and humidity controlled room (20 °C/50% relative humidity) prior to the commencement of processing trials.

Other samples of rice were also obtained and evaluated:

- **Control-A**. FD rice manufactured by DSTO-Scottsdale (using SunRice Parboiled rice) during the previous 12 months. This was used as the laboratory scale control.
- **Control-B**. SunRice Parboiled rice, freshly cooked in the DSTO-Scottsdale production facility using the kettle method (see section 3.2.1 below). This was used as a production scale control.
- **Control-C**. FD rice manufactured by DSTO-Scottsdale (using SunRice Parboiled rice) in the same freeze dryer batch as the production scale trial. This was the same product as Control-B but processed through to freeze drying. It was used as a production scale control.
- **COTS-A**. A COTS, freeze dried, instant rice product (within best-before date by 24 months) purchased from an outdoors supply business.

3.2. Methods

3.2.1. Cooking of rice

The selection of water to rice (W:R) ratio was based on the cooking instructions provided on the package. However, rice was rinsed only when using the stove top cooking method.

- **Stove top method**. Following the instructions on the rice packets, the rice was rinsed prior to cooking. The rice was cooked in excess boiling water (W:R ratio 8:1 volume/volume (v/v)). Rice was added to the boiling water; after the water had returned to the boil, at 3-minute intervals a small amount of rice was removed by strainer and rinsed gently with cold tap water for one minute to stop further cooking, then drained and tested for 'doneness' (see below).
- **Rice cooker (absorption) method.** Two types of rice cooker were used, one for the initial part of laboratory scale work (domestic, 10-cup rice cooker, model RC4750, Sunbeam) and another for the laboratory scale sensory evaluation and the production scale work (commercial, 50-cup rice cooker, model ERC9L, Auscrown). The following W:R ratios (v/v) were used: 1.3:1 for Jasmine; 1.6:1 Basmati and Calrose, and 1.8:1 for Parboiled and Brown. After adding water to rice, the rice cooker was switched on to cook and allowed to run until it automatically switched over to the 'keep warm' mode. The rice cooker was allowed to remain in 'keep warm' mode for 10 minutes. The rice cooker bowl was then removed from the laboratory scale rice cooker for further cooling. In the case of the production scale rice cooker, the rice was removed to a tray for cooling with the assistance of fans for one hour.
- **Kettle method.** Steam jacketed kettles are routinely used to cook rice in the DSTO-Scottsdale production facility. Sunrice Parboiled long grain rice was added to a boiling mixture of W:R:salt ratio 3:1:0.009. The rice was stirred continuously and once the mixture returned to the boil was cooked for seven minutes, with frequent stirring. The rice was strained, rinsed with cold water and strained, repeating the rinsing and draining steps twice. The cooking time is deliberately short to leave the grain less than fully cooked, with the purpose of obtaining a final product (post freeze drying) that is sufficiently strong to withstand packing, storage and

distribution. Anecdotally, rice that has been fully cooked and freeze dried will deteriorate to rice dust and be unsuitable for its intended purpose as a component of CRP, however to our knowledge, this claim has not been substantiated.

- **COTS-A method.** COTS-A was purchased as a fully processed product; the cooking method was not known to the authors.

The cooking time was dependent on the water absorption of the kernels which differs naturally among rice types. A test for 'doneness' may be performed by pressing a few grains between two glass slides; the optimum cooking time being reached once the uncooked opaque core disappeared (Figure 1). This was used with the stove top method to identify 'doneness', and with the rice cooker method as reassurance that the rice cooker was performing correctly.

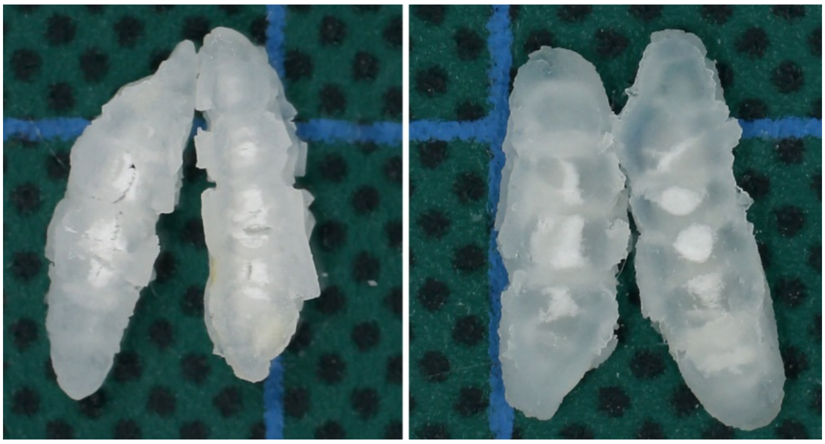

Figure 1. Test for 'doneness' showing grains with opaque, uncooked cores (left, Basmati; right, Parboiled). When fully cooked the entire grain will have the translucent appearance of the sides and ends of the grains shown in the image.

3.2.2. Freeze drying and packing of freeze dried rice

- **Laboratory scale**. Cooked and cooled rice was transferred to stainless steel trays to a depth of 1.5 cm, placed in a –80 °C freezer for 2 hours, then transferred to the laboratory scale freeze dryer (Christ, model Epsilon 2-4). The freeze drier was programmed to 'main dry' at 5 °C for 24 hours, followed by 'final dry' at 15 °C for 2 hours.

- **Production scale**. Cooked and cooled rice (rice cooker method) and cooked and rinsed rice (kettle method) were transferred to aluminium trays to a depth of 1.8 cm, placed in a –20 °C blast freezer and held overnight, then transferred to the production scale freeze dryer (Pilot Freeze Drying Plant, Budge-Ellis Staff Co-operative Ltd, Silverwater, NSW). The rice was dried using the routine profile (Figure 2) for FD rice. Note that the profile provides for a total drying time of 8 hours, although drying may be finished sooner and the process terminated accordingly.

- On completion of drying, the FD rice was packed in vacuum sealed bags to protect from moisture absorption. All packed samples were stored in a 20 °C/50% relative humidity room while awaiting analysis.

Samples of Control-A and COTS-A were obtained in their standard, ambient pressure packets (i.e. not vacuum packed). Samples of Control-C were vacuum packed.

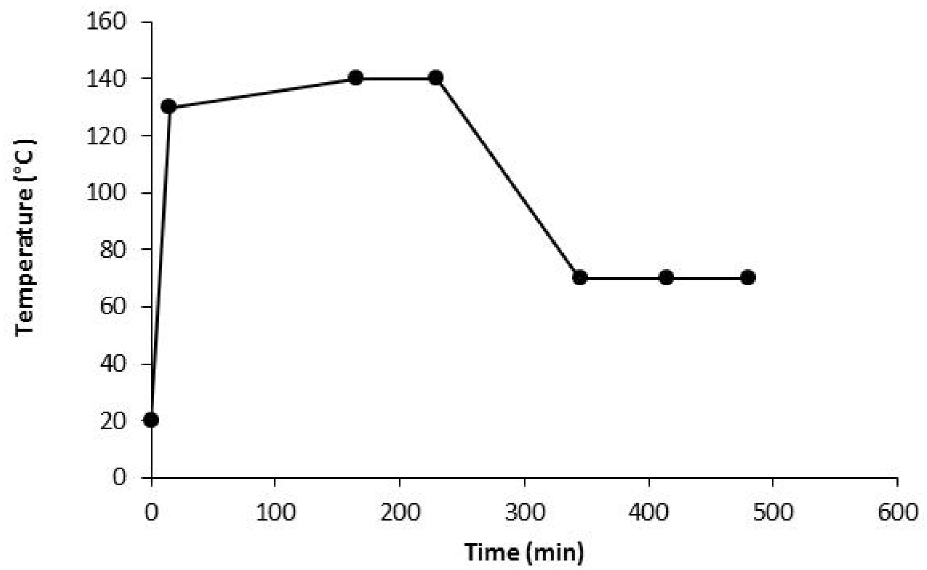

Figure 2. Freeze drying profile used to manufacture freeze dried rice (Controls-A and C)

3.2.3. Rehydration of freeze dried samples

Rehydration was performed by adding 250 mL of water at a defined temperature to a cup containing 30 g of FD rice sample, and stirring gently. The cup and its contents were placed in a bain-marie set at 30 °C and held for a defined period of time. At the end of the rehydration time, the rice was transferred to a strainer. The strainer was swirled gently (3 times), followed by knocking gently (3 times); repeating the knocking and swirling steps twice (a total of 3 times) to remove excess water prior to transferring the rehydrated rice to small cups with lids prior to analysis.

Samples from both project parts were rehydrated using water at 90±1 °C for 10 and 15 minutes. Samples of Parboiled and Control-A from part one were also rehydrated in water at 30±1 °C, 60±1 °C and 90±1 °C for 10, 15 and 20 minutes, and evaluated using a response surface approach.

3.2.4. Moisture determination

- **Vacuum oven method**

  The moisture content of freshly cooked and rehydrated rice samples was determined using an in-house method based on AOAC Official Method 925.45D [3]. Sample mass was approximately 2 g, and samples were dried overnight under vacuum at 70 °C with redrying to constant weight (change in weight <2 mg), with each sample tested in duplicate.

- **Karl Fischer method**

  The moisture content of FD rice samples was determined by Karl Fischer titration using an in-house method based on AOAC Official Method 2001.12 [3]. Prior to analysis, the samples were ground in a grinding mill (ZM 200, Retsch GmbH, Haan, Germany), working quickly to minimise the risk of absorption of atmospheric moisture. Titrations were performed in 2:1 methanol:formamide (Sigma Aldrich) using Hydranal Composite 2 as the titrant (Sigma Aldrich). Following standardisation of the titrant with sodium tartrate, 200 mg of ground FD rice was stirred for 5 minutes then titrated to dryness, with each sample tested in triplicate.

3.2.5. Texture measurement

Texture profile analysis (TPA), an instrumental method, is a double compression test for measuring textural properties of foods. This is sometimes called the 'two bite test' as it provides an approximation of the biting action when food is chewed. Among a range of texture parameters obtained from TPA analysis, hardness, cohesiveness and springiness are most relevant to rice and were selected for this study (Table 2).

Table 2. Definitions of texture parameters

Texture parameter	Definition	Reference
Hardness	Force required to compress a food between the molars. Defined as force necessary to attain a given deformation.	Brookfield Engineering website[1]
Cohesiveness	A measurement of how well the structure of a product withstands compression. The strength of internal bonds making up the body of the product (the greater the value the greater the cohesiveness).	Brookfield Engineering website
Springiness	How well a product physically springs back after it has been deformed during the first compression.	Texture Technologies website[2]

[1] www.brookfieldengineering.com
[2] www.texturetechnologies.com

TPA of rice was performed using a texture analyser (TA Plus, Texture Analysis Machine, Lloyd Instruments, UK) fitted with a 100 N load cell. The software (Nexygen Plus) was upgraded between part one and part two of the project. A sample of 3 whole grains of rice was compressed to 70% with a rod-type probe (1.2 cm diameter) at a speed of 1.0 mm/s [4, 5]. An advantage of the 3-grain method for the laboratory scale evaluation was that relatively small amounts of sample were available for testing. Due to within sample variation, at least 10 readings were collected for each sample.

3.2.6. Sensory evaluation

A round table discussion, with eight experienced panellists, was conducted for the laboratory scale trial. Samples of the laboratory scale trial, Control-A and COTS-A were rehydrated and evaluated in terms of aroma, texture, flavour and overall acceptability. Rehydration for all samples was based on the instructions printed on the packet of Control-A, i.e. add 150 mL of hot water to 55 g of freeze dried rice and allow to stand for 15 minutes then drain.

3.2.7. Environmental scanning electron microscopy

The structure of raw and FD rices was observed with an environmental scanning electron microscope (Quanta 200, FEI, Oregon, USA). Rice grains were fractured manually across the mid-point of the grain and the grain half to be examined was mounted on an aluminium stud using double-sided adhesive tape with the snap surface face up. Grains to be examined externally were mounted as whole grains with the length of the grain parallel to the face of the aluminium stud. The ESEM conditions were set to an accelerating voltage of 15 kV, pressure 0.5 Torr, spot size 4.0 nm and working distance 5 mm.

3.2.8. Statistical analyses

Student's t-test was used to identify significant differences for the majority of measurements.

Parboiled rice and Control-A were examined using a central composite design to determine the relationships between the independent variables of rehydration time and temperature, and the responses of hardness, cohesiveness, springiness and moisture. A response surface methodology was used with measurements based on 13 combinations including 5 centre points. Analysis of variance was used to identify significant differences.

Differences were considered significant if $p<0.05$, highly significant if $p<0.001$ and very highly significant if $p<0.0001$.

4. Results and discussion

4.1. Laboratory scale evaluation

4.1.1. Cooking rice

4.1.1.1. Stove top method

Jasmine, Basmati and Calrose grains required less cooking time than Parboiled and Brown rices (~12–15 minutes and 18–25 minutes, respectively). Rice starch leached out while boiling, thus the longer it was boiled, the paler and more transparent the rice appeared. In addition, the appearance was unappealing due to splitting and busting open of grains, mainly with soft and Brown rices, less so with Parboiled rice. The cooked rice was watery and tasteless (Figure 3). Malaker and Baneerjee [6] demonstrated a loss of nutrients (minerals and water soluble vitamins) upon washing[3] and cooking in excess water which is then discarded[4], with these losses increasing when the rice was cooked with a greater volume of water. Leelayuthsoontorn and Thipayarat [7] reported a significant effect on the exterior integrity, texture and colour of Jasmine rice when the rice was boiled.

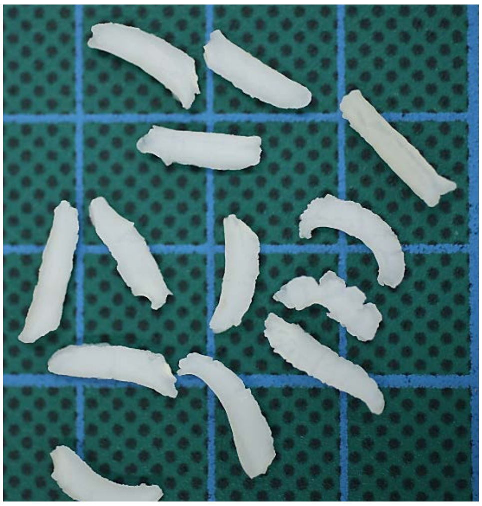

Figure 3. Basmati rice cooked on stove for 12 minutes using excess water; note damaged surface

4.1.1.2. Rice cooker method

The rice cooker method produced cooked rice that appeared slightly drier on the surface and bottom and moist in the middle. In the cases of Brown and Parboiled rices, a thin layer of partially caramelized rice was observed at the bottom of the pot on completion of cooking,

[3] Losses of 5% thiamine, 17% riboflavin, 9% niacin, 10% calcium, 5% phosphorus, 4% phytin phosphorus, 21% iron, 25% available iron and 2.3% nitrogen.
[4] Losses of 20% thiamine, 27% riboflavin, 30% niacin, 17% calcium, 17% phosphorus, 11% phytin phosphorus, 18% iron, 20% available iron and 5% nitrogen.

however the rice which was in contact with that partially caramelised layer at the bottom of the pot was still moist. When Calrose and Brown rices were being cooked, starchy liquid bubbled around the rice cooker lid and overflowed slightly. This was not observed when cooking the other types of rice.

Cooking time for Jasmine, Basmati and Calrose rices was ~ 20–22 minutes (domestic rice cooker) and 26–28 minutes (commercial rice cooker); Brown and Parboiled rices took 30–32 minutes (domestic rice cooker); and ~37–39 minutes (commercial rice cooker). This is consistent with other studies that have shown that Parboiled rice takes longer to cook than raw (non-parboiled) rice [8, 9, 10], typically, at least 1.5 times as long [11]. Parboiled rice can absorb more water than non-parboiled rice without losing its shape due to its higher swelling ratio. Since parboiling and consequent gelatinisation harden the grain, it needs a longer time to cook to a soft consistency and swells more during this period without disintegration of cell walls [10].

4.1.2. Evaluation of freshly cooked rice

Observations on freshly cooked rice are summarised in Table 3.

Table 3. Observations on freshly cooked rice using the rice cooker method

Rice type	Observation
Jasmine	Fragrant, fluffy, soft, moist, slightly sticky with intact grains.
Basmati	Fragrant, long slender grain and soft. However it was a bit firmer, drier and less sticky than Jasmine rice.
Calrose	Fragrant, soft, moist. It was much stickier than Jasmine rice, tends to clump, difficult to spread on tray, may not be suitable for freeze drying.
Brown	Moist, nutty flavour, easy to spread on tray, very chewy texture.
Parboiled	Unpleasant flavour, moist, outer surface was dry, not sticky, firm and chewy.

It was observed that using the rice cooker was no more time consuming overall than the stove top method, as there was no need to wait for the water to come to the boil initially. The rice cooker method gave more reproducible results, possibly through allowing the starch to become fully gelatinised resulting in better colour, flavour, texture as well as physical integrity of the grain. The soft rice types (Jasmine, Basmati and Calrose grains) retained a delicate aromatic aroma and flavour after cooking; similarly Brown and Parboiled rice also retained their characteristic flavours (sweet and nutty flavours for Brown; acidic aroma and flavour for Parboiled rice). Therefore, commercial rice cookers were used for part two of this project.

4.1.3. Evaluation of rehydrated FD rice: TPA and moisture

The cooked rices were freeze dried using the laboratory scale freeze dryer as described in section 3.2.2. Samples of FD rices (Jasmine, Basmati, Brown, Calrose, Parboiled, COTS-A and Control-A) were rehydrated in hot water (90±1 °C) for 10 and 15 minutes. TPA was not performed on the COTS-A sample due to significant breakage of the grains (estimated at

>80%), casting doubt over the applicability of the 3-grain method which relies on the use of intact grains.

Table 4 summarises the effect of rehydration time on TPA parameters, while figures 4–6 provide more detailed information.

Table 4. Effect of rehydration time (10 vs 15 minutes) on texture and moisture of FD rices

Texture parameter	**Rice cooker**					**Kettle**
	Jasmine	Basmati	Calrose	Brown	Parboiled	Control-A
Hardness (N)						
Cohesiveness						
Springiness (mm)						
Moisture (%)						

	Significantly different (10 vs 15 minutes rehydration, p<0.05)

Although not always significant, there was a trend to lower values for hardness, cohesiveness and springiness when rehydration time was increased from 10 minutes to 15 minutes.

A high degree of measurement uncertainty has been associated with food texture measurements and is considered normal for natural products [12, 13]. The standard deviations obtained in this work appear to be high at times, possibly due in part to differences in conditions in different parts of the rice cooker, for example the development of a thin layer of slightly caramelised rice at the bottom of the cooker is indicative of a temperature gradient in the rice cooker. Natural biological variation from one grain to the next may also be expected. The 3-grain technique may be particularly sensitive to uncertainty arising from within sample variation. Therefore, where practical, alternative techniques using larger sample sizes will be considered for future studies.

Based on the hardness results the rices may be divided into three groups: soft rices (Jasmine, Basmati and Calrose); firm rice (Parboiled); and very firm rice (Brown). The hardness of Brown rice was significantly greater than that of all other rices (Fig. 4). The main contributor to this would be the bran layer which gives Brown rice its characteristic firmness.

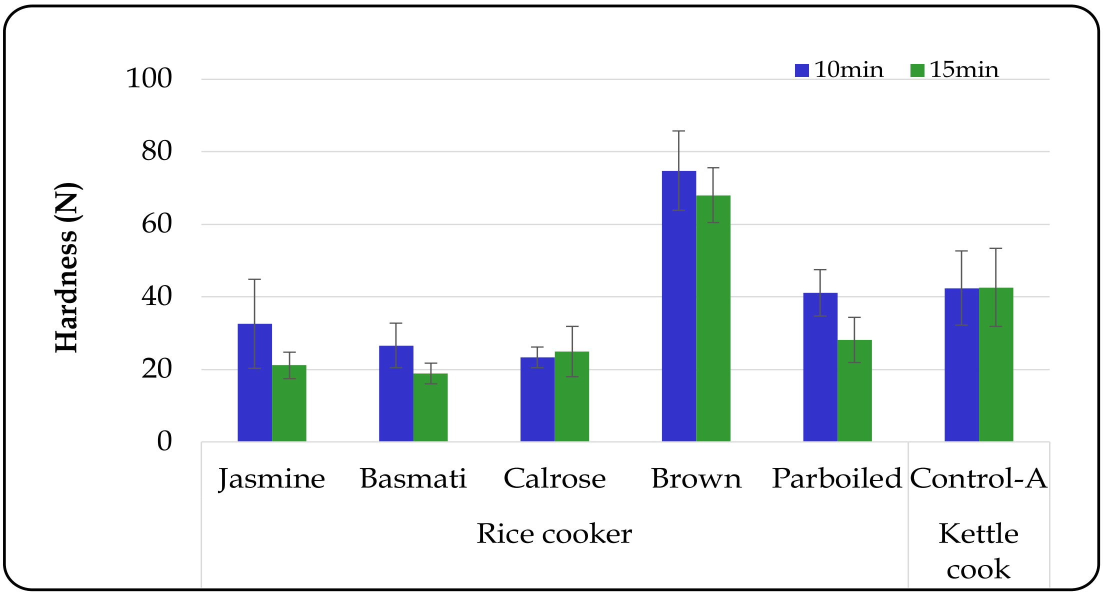

Figure 4. Hardness of freeze dried samples rehydrated at 90±1 °C for 10 and 15 minutes.

The medium grain and Parboiled rices had higher cohesiveness and springiness values than the long grain rices Jasmine and Basmati. Control-A was of similar cohesiveness to the soft long grain rices, and of comparable springiness to Basmati but higher than Jasmine.

There were significant differences in the absorption of moisture in Parboiled (higher) compared to Control-A when samples were rehydrated for 10 min, along with higher cohesiveness and springiness in Parboiled compared to Control-A (Figs 5 and 6).

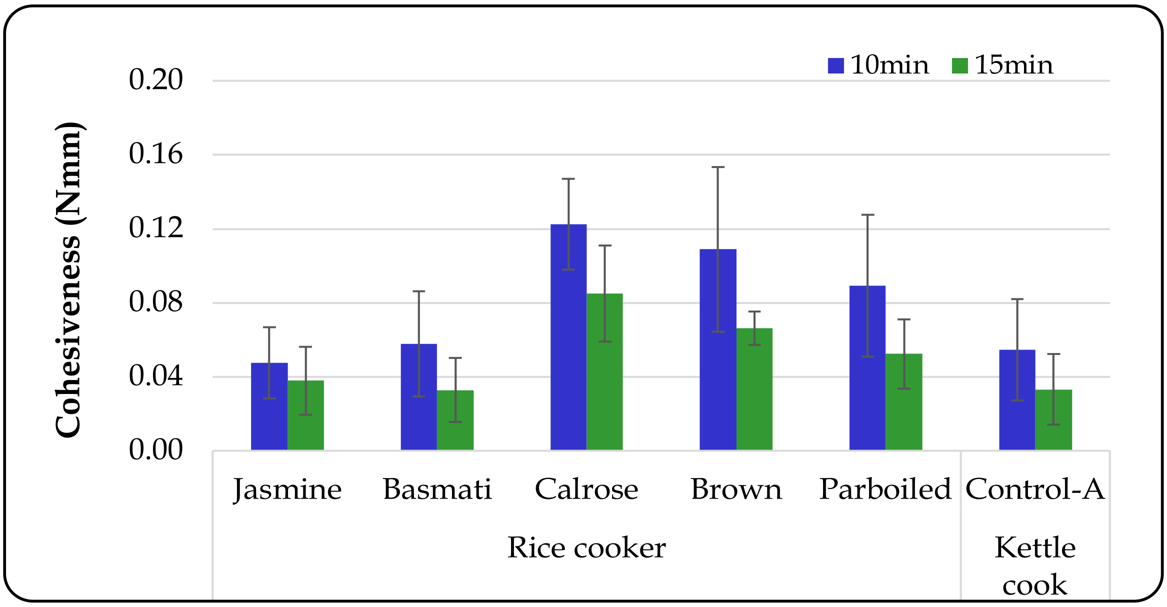

Figure 5. Cohesiveness of freeze dried samples rehydrated at 90±1 °C for 10 and 15 minutes

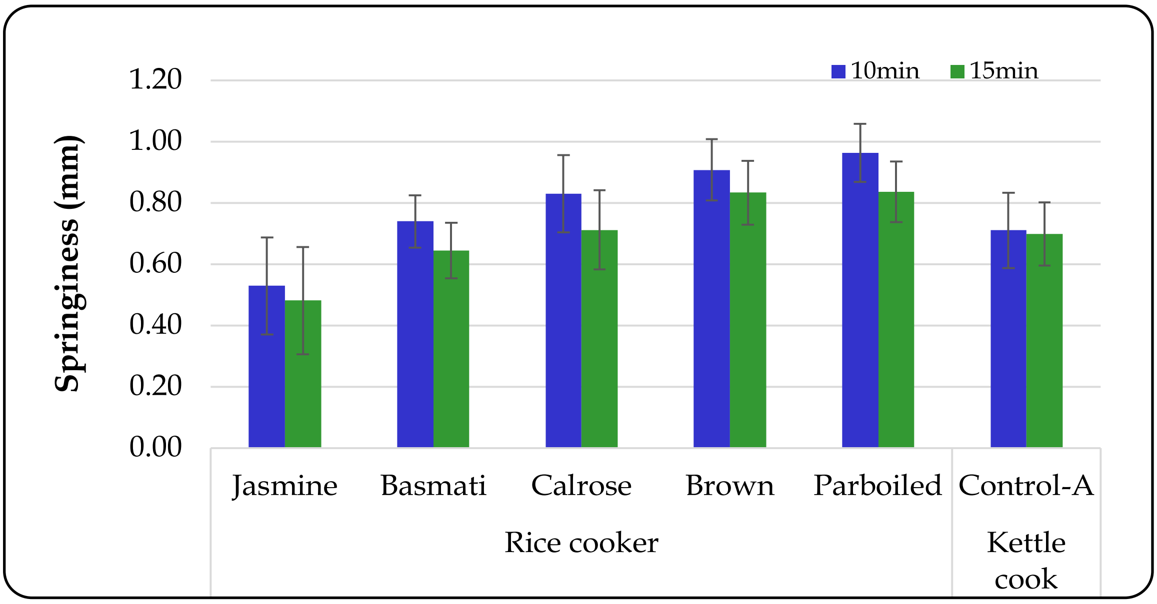

Figure 6. Springiness of freeze dried samples rehydrated at 90±1 ℃ for 10 and 15 minutes

The hardness of Brown rice may be related to the moisture content which was significantly lower ($p<0.05$) than that of Control-A (Figure 7). The bran layer of Brown rice has been linked to a slower rate of water penetration into the endosperm compared to the milled grains of two Japonica cultivars [14]. After 10 minutes rehydration, Basmati and Parboiled had absorbed significantly more water than Control-A.

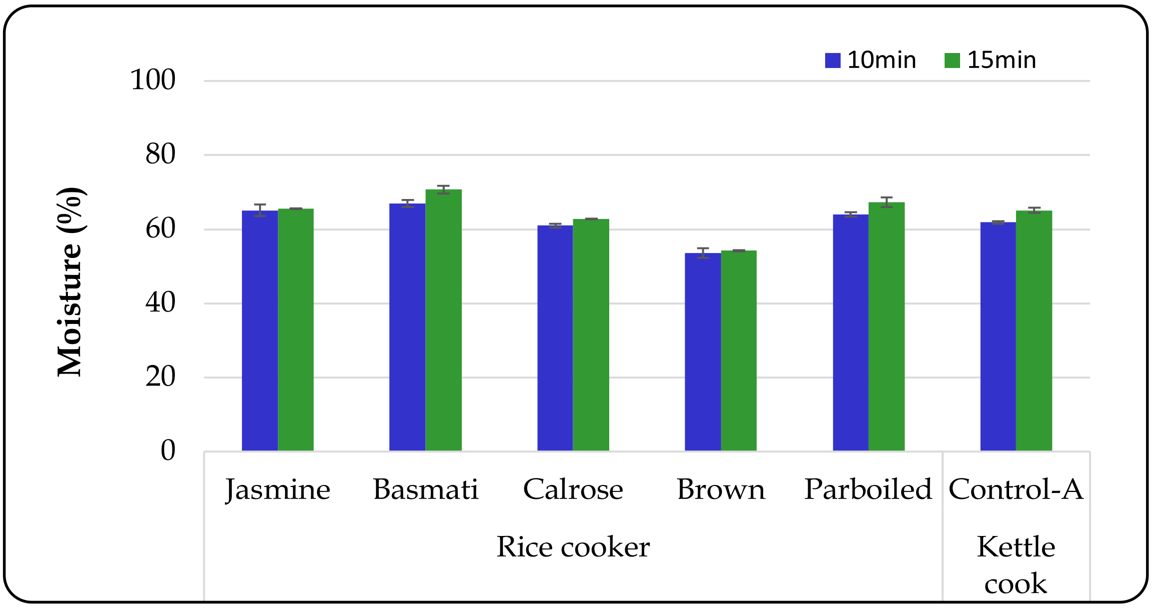

Figure 7. Moisture of freeze dried samples rehydrated at 90±1 ℃ for 10 and 15 minutes

4.1.4. Selection of preferred rice types

Based on the results obtained to this point in the project, the number of rice types was reduced before continuing the evaluation and moving on to part two. This was for reasons of practicality and efficiency, and sufficient results had been obtained to allow an informed selection of the preferred rice types.

The softer rices, Jasmine, Basmati and Calrose were comparable in terms of flavour and texture when fresh; when freeze dried and rehydrated, hardness was very similar but Calrose had higher values for cohesiveness and springiness. In terms of ease of cooking and traying up for freeze drying, Jasmine and Basmati were more suitable than Calrose. The decision was made to continue with Jasmine and Basmati only.

The firmer types, Brown and Parboiled, when rehydrated were similar in cohesiveness and springiness, but the Brown rice was harder. When freshly cooked, the Brown rice was found to have a very chewy texture, a characteristic which may limit popularity amongst consumers, the majority of whom may be more familiar with the commonly eaten softer rices. The flavour of Brown rice was described favourably, whereas Parboiled was considered as 'unpleasant'. However, this potential advantage of Brown rice over Parboiled may be short-lived, as Brown rice is recognised as being susceptible to the development of rancidity due to the oils present in the bran layer. By a slim margin, Parboiled was judged more suitable than Brown rice for retention in this project.

The remainder of the part one evaluation is limited to Jasmine, Basmati, Parboiled, control samples and, to a lesser extent, COTS-A.

4.1.5. Sensory evaluation

A round table sensory discussion was conducted to evaluate rehydrated samples of the selected varieties: Jasmine, Basmati and Parboiled, as well as Control-A and COTS-A. The results are summarised in Table 5.

Jasmine and Basmati retained pleasant aroma and flavour, while Parboiled and Control-A had unpleasant acidic aromas and flavours. It was considered that Jasmine and Basmati could have been rehydrated in less time, i.e. in less than 15 minutes.

COTS-A was observed to have a rancid aroma when the packet was opened, as well as following rehydration. Oil, listed as an ingredient—possibly added to stop grains sticking together—is considered to be the source of the rancidity.

Table 5. Summary of sensory evaluation results

FD rice type	Comments
Jasmine	Pleasant flavour, moist, fluffy, pleasing soft texture. Could be rehydrated using less water and less time.
Basmati	Pleasant aroma and taste, good flavour, good texture with slight resistance on bite.
Parboiled	Dry on palate, however, better taste and texture than 'Control-A' sample. Good, firm grains but not pleasant in terms of flavour (acidic).
Control-A	Powdery, dry mouthfeel, lack of rice flavour. A lot of variation in texture. About 1/3 quantity retains whole grain structure, the rest was either broken or split after rehydration.
COTS-A	Very soft, almost mushy, majority of grains were broken (>80%, like Asian 'broken rice'. Lack of rice flavour, rancid with synthetic/plastic aroma and flavour.

4.1.6. Comparison between Parboiled and Control-A

A more detailed series of rehydration tests with texture and moisture measurements based on a central composite design (see section 3.2.8) were undertaken to compare the FD parboiled rice and Control-A. Samples were rehydrated for 10, 15 and 20 minutes in water at 30, 60 and 90±1 °C. Figure 8 shows the response surface charts of hardness, cohesiveness and springiness versus rehydration time and temperature. The charts are based on quadratic models which provided the best fits across the range of measures that were evaluated.

In general, the hardness, cohesiveness and springiness of rehydrated rice decreased as rehydration time and temperature increased. The hardness of rehydrated FD Parboiled rice was significantly associated with rehydration time ($p=0.0205$) and temperature ($p=0.0012$), whereas the hardness of Control-A was significantly associated with rehydration temperature only ($p=0.0044$).

The cohesiveness and springiness of rehydrated FD Parboiled rice were significantly ($p<0.05$) associated with rehydration time ($p=0.0029$ and 0.0129 respectively) and rehydration temperature ($p<0.0001$ and 0.0043 respectively). Aside from hardness, the only other significant TPA relationship found with Control-A was between springiness and rehydration temperature ($p=0.0152$). Hardness, cohesiveness and springiness response surfaces bear similarities to those obtained for moisture.

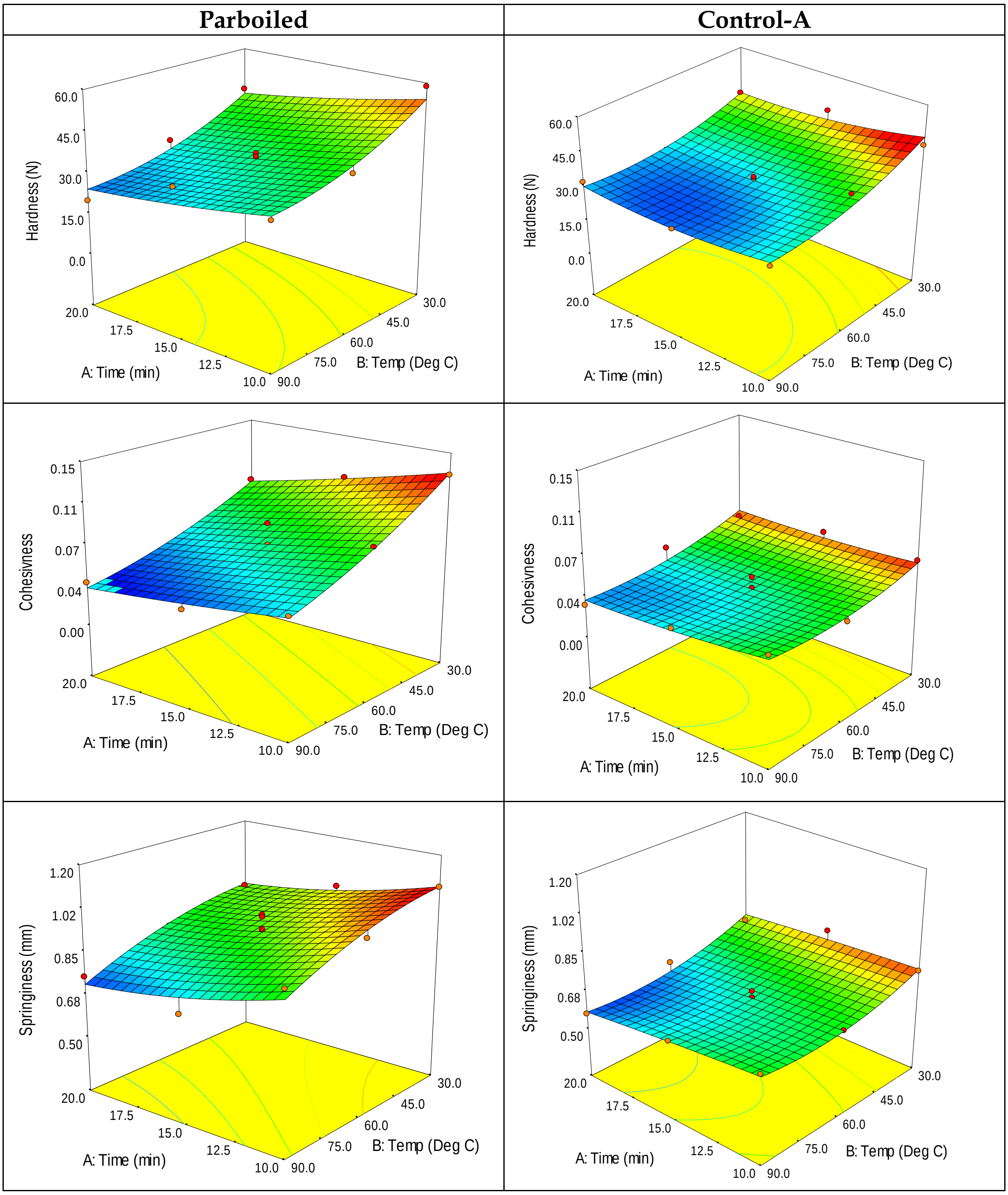

Figure 8. Response surface for the effect of rehydration time (min) and temperature (℃) on hardness, cohesiveness and springiness of Parboiled rice and Control-A

Figure 9 presents the response surfaces for moisture content versus rehydration time and temperature. The moisture content of rehydrated Parboiled rice increased significantly with time ($p=0.0011$) and very highly significantly with temperature ($p<0.0001$). Similarly, Control-A moisture content increased significantly with time ($p=0.0311$) and very highly

significantly with temperature (p<0.0001). However, the response surface indicates that Control-A had plateaued whereas Parboiled appears to have further capacity for water absorption at maximum temperature and time.

The greater water uptake by FD Parboiled is likely to be related to its longer cooking time, compared to the short cooking time for Control-A which leaves the latter undercooked and not fully gelatinised. This is considered to be a key reason for the weaker relationships between texture and rehydration time and temperature observed with Control-A compared to Parboiled.

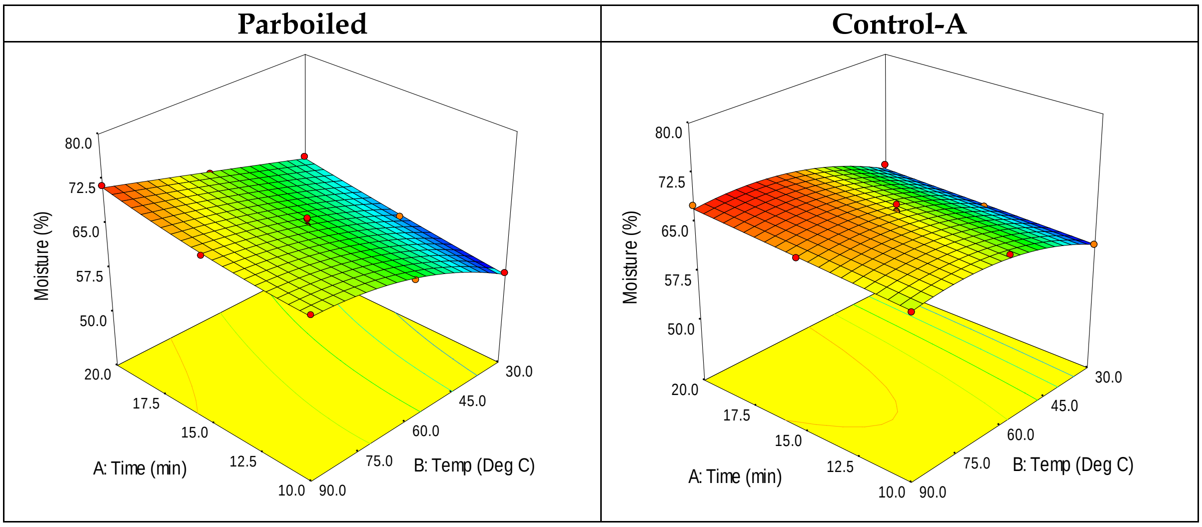

Figure 9. Response surface for the effect of rehydrated time (min) and temperature (°C) on moisture of Parboiled and Control-A

4.2. Production scale trial

Part two of this study involved cooking the selected varieties—Basmati, Jasmine and Parboiled rice—using commercial kitchen rice cookers, then freeze drying using the production scale freeze dryer. This trial was conducted on the same day that the production facility manufactured FD rice for CRP, so the trial samples were subjected to normal production freeze drying conditions. Samples of the production line product were collected as controls for part two: fresh kettle cooked rice – Control-B (to compare with the freshly cooked samples); and FD rice – Control-C (to compare with the FD samples).

4.2.1. Evaluation of freshly cooked rice

Images of grains of the freshly cooked rices are shown in Figure 10.

Figure 10. Samples of freshly cooked rice: Control-B (Parboiled, kettle cooked) and Parboiled (left); Jasmine (middle) and Basmati (right, using rice cooker)

In the rice cooker, Parboiled took longer to cook compared to Jasmine and Basmati. Freshly cooked Jasmine and Basmati rices were whitish and had pleasant sweet aromas. Both types tended to stick and clump when spread on freeze dryer trays, with Jasmine being stickier than Basmati.

In contrast, Parboiled rice cooked in the rice cooker retained its pale amber/buff colour and acidic aroma, had an intact structure, was firm, fluffy, non-sticky and free-flowing making it easy to spread on the freeze drying tray. The fact that the rice was free-flowing when cooked in the rice cooker, suggests that the washing steps usually employed when kettle cooking Parboiled rice in the DSTO-Scottsdale production facility may not be necessary to facilitate spreading the product on freeze dryer trays.

Grains of all rice types were found to have split lengthwise to some extent during cooking.

The results of TPA conducted on samples of the freshly cooked rice are presented in Figure 11. There were no significant differences between two consecutive days, therefore the data (n=20 for each parameter) were pooled for evaluation and presentation.

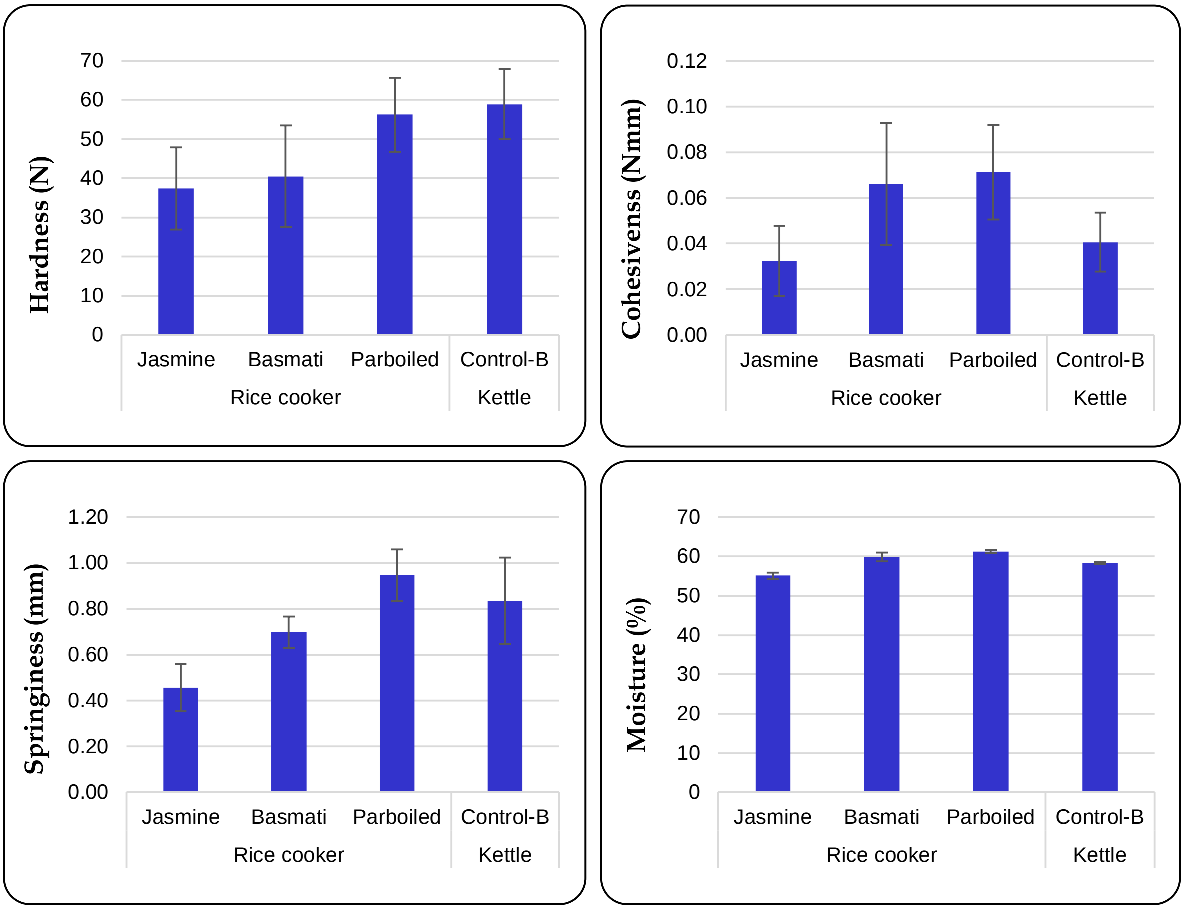

Figure 11. TPA and moisture content of freshly cooked rice samples

The moisture content of freshly cooked rice is dependent on the extent of gelatinisation of the grain. The moisture contents of Jasmine and Parboiled rices were significantly different to that of Control-B ($p<0.05$).

Although there was no significant difference between the moisture contents of Basmati and Control-B, TPA revealed significant differences between the two for all texture attributes: Basmati had a lower hardness value but higher cohesiveness and springiness values compared to Control-B. The hardness and springiness of Jasmine rice was also significantly different to that of Control-B, the Jasmine rice values being lower in both cases.

The cohesiveness and springiness values obtained for Parboiled rice were significantly higher than those of Control-B, whereas the hardness of Control-B was higher—but not significantly so—than Parboiled.

4.2.2. Evaluation of freeze dried rice

Images of the FD rice were taken soon after completion of a freeze drying run (Figure 12). The FD rices still retained their characteristics in terms of colour and aroma. There was no clumping of Parboiled and Control-C, whereas a small degree of clumping was observed with Basmati and more with Jasmine. However, when rehydrated the clumps rapidly and easily disintegrated into individual grains. Control-C and Parboiled differed in colour post-cooking due to the different techniques used, and the difference became more pronounced after freeze drying.

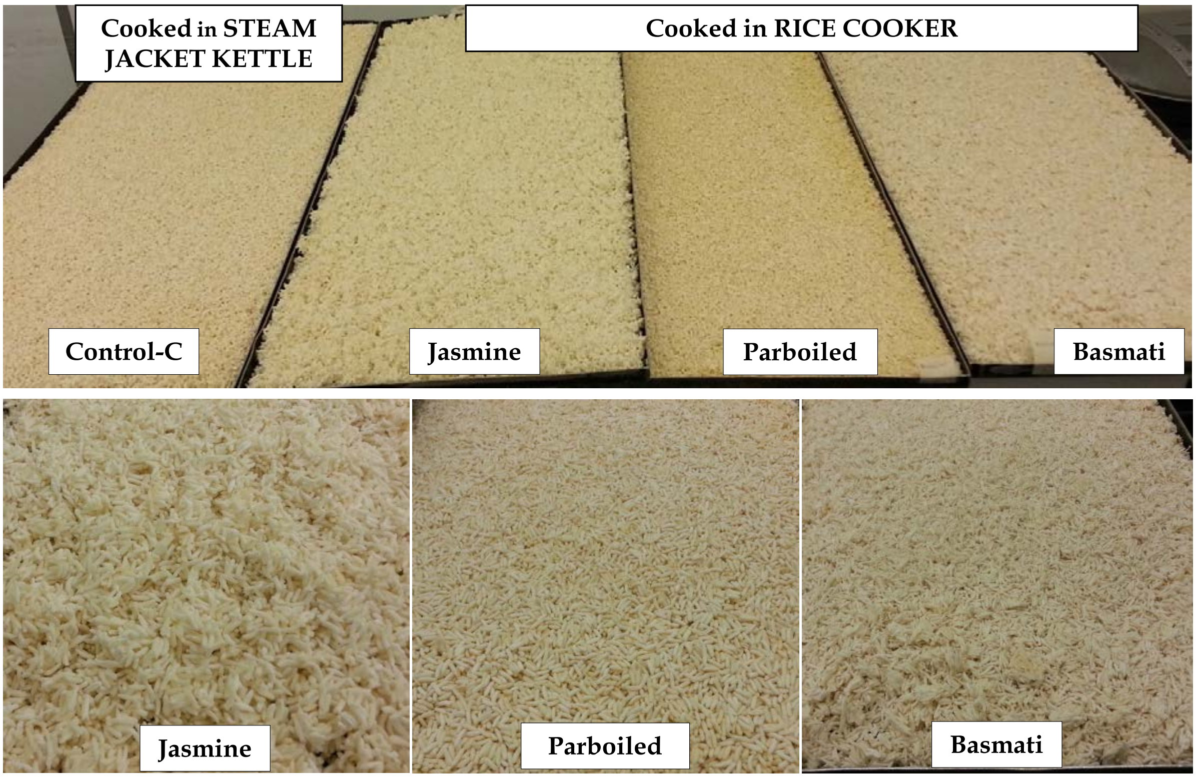

Figure 12. Freeze dried rice produced using the production scale freeze dryer

4.2.3. Evaluation of rehydrated freeze dried rice

4.2.3.1. Texture profile analysis

FD rice samples were rehydrated in hot water (90±1 °C) for 10 and 15 minutes and analysed to determine hardness, cohesiveness, springiness and moisture content (Figure 13).

The only significant differences associated with rehydration time were for moisture and springiness of Jasmine rice. This suggests that 10 minutes rehydration time in hot water would be sufficient prior to consumption. Jasmine and Basmati rices absorbed significantly more water (71.8% and 72.1% respectively after 10 minutes) than Parboiled and Control-C (68.1% and 69.4% respectively).

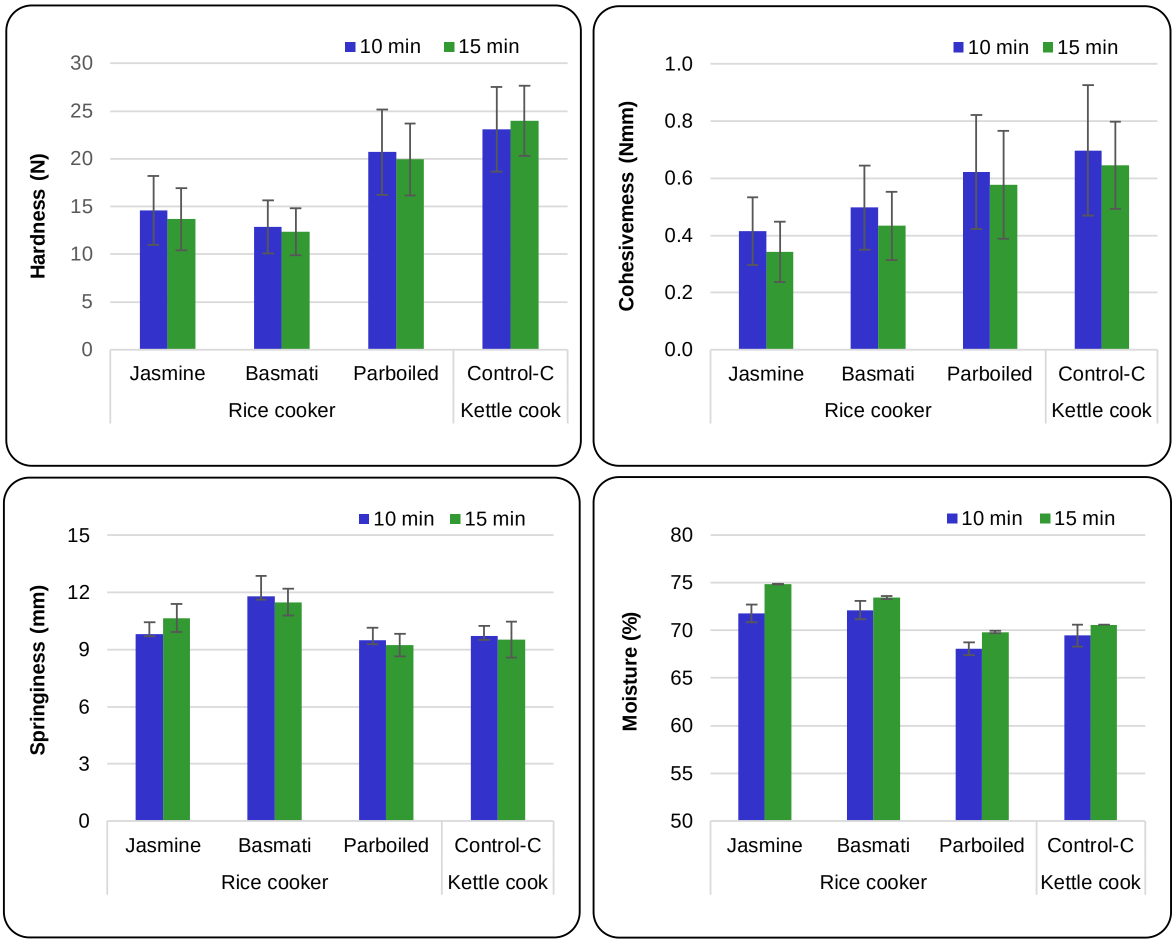

Figure 13. TPA results and moisture content of rehydrated freeze dried rice samples

There were significant differences in the moisture contents of Control-C and production scale samples when rehydrated for 15 min ($p<0.05$). This was probably a contributor to the significant difference in hardness between Control-C (firmer) than the other rices. This is consistent with the centres of the Control-C grains being not fully cooked (see section 3.2.1 and Figure 14). The practice of undercooking the rice has a negative effect on the quality of the freeze dried product. The springiness and cohesiveness of Control-C was significantly different to the springiness and cohesiveness of Jasmine and Basmati, but not Parboiled.

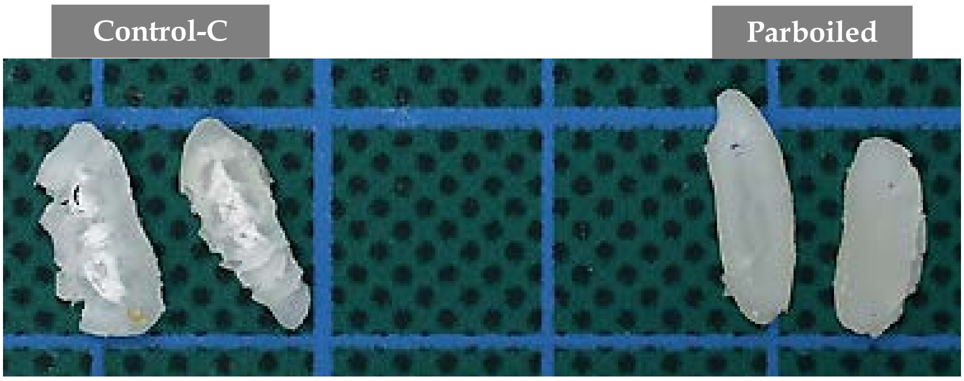

Figure 14. Images of rice after TPA following rehydration in hot water for 10 minutes. The centres of the Control-C grains appear to be dry and not gelatinised, whereas the Parboiled grains appear hydrated/gelatinised.

4.2.3.2. Sensory evaluation

A round table sensory discussion was conducted to evaluate the rehydrated production scale samples. The results are summarised in Table 6.

Table 6. Summary of sensory evaluation results

FD rice type	Comments
Jasmine	White creamy colour; slightly sweet pleasant flavour; moist; some broken grains; soft to very soft texture; not much springiness; small degree of grittiness and chalkiness.
Basmati	Whitish/greyish colour; mild sweet aroma and flavour; some breakage of grains; slight resistance on bite (springiness), nice firmness, good overall quality.
Parboiled	Large/full, long and intact grains; creamy/buff colour; soft but slightly dry and gritty; little flavour, earthy.
Control-C	Slightly creamy colour, high proportion of split and bust grains; very gritty, powdery and chalky; flavourless.

The rehydrated FD Jasmine and Basmati rices still retained some of the characteristic colours and aromas of freshly cooked rice, but the aromas were much weaker. Parboiled and Control-C retained much of the unpleasant sour, acidic aromas, as well as the colour, of freshly cooked Parboiled rices. Jasmine had the greatest degree of broken grains, with breakage of Basmati grains occurring to a lesser degree. Parboiled rice held its structure with very little breakage. The grains of Control-C were broken, cracked and split open along the length of the grain.

The majority of panellists preferred the flavours of Jasmine and Basmati (both slightly sweet) rather than Parboiled (earthy, starchy) and Control-C (bland). Basmati was described in the most favourable terms as having a degree of firmness (medium), springiness (slightly) and the least grittiness. Jasmine was described as moist, however it had a soft to very soft

texture. Parboiled was quite firm, springy, slightly dry and gritty. Control-C was powdery, chalky and very gritty.

The difference between Parboiled and Control-C was the cooking method; recall that they are the same Parboiled rices and both were freeze dried in the production scale freeze dryer. Section 4.1.1.1 included discussion of the poor quality product resulting from stove top cooking—a domestic and laboratory equivalent of kettle cooking. This cooking technique, which in the production facility included frequent stirring and multiple washes at the end of cooking, is evidently a significant factor in the sensory observations reported for Control-C in Table 6.

4.2.4. ESEM analysis

Figure 15 shows ESEM images of uncooked Parboiled rice in cross section.

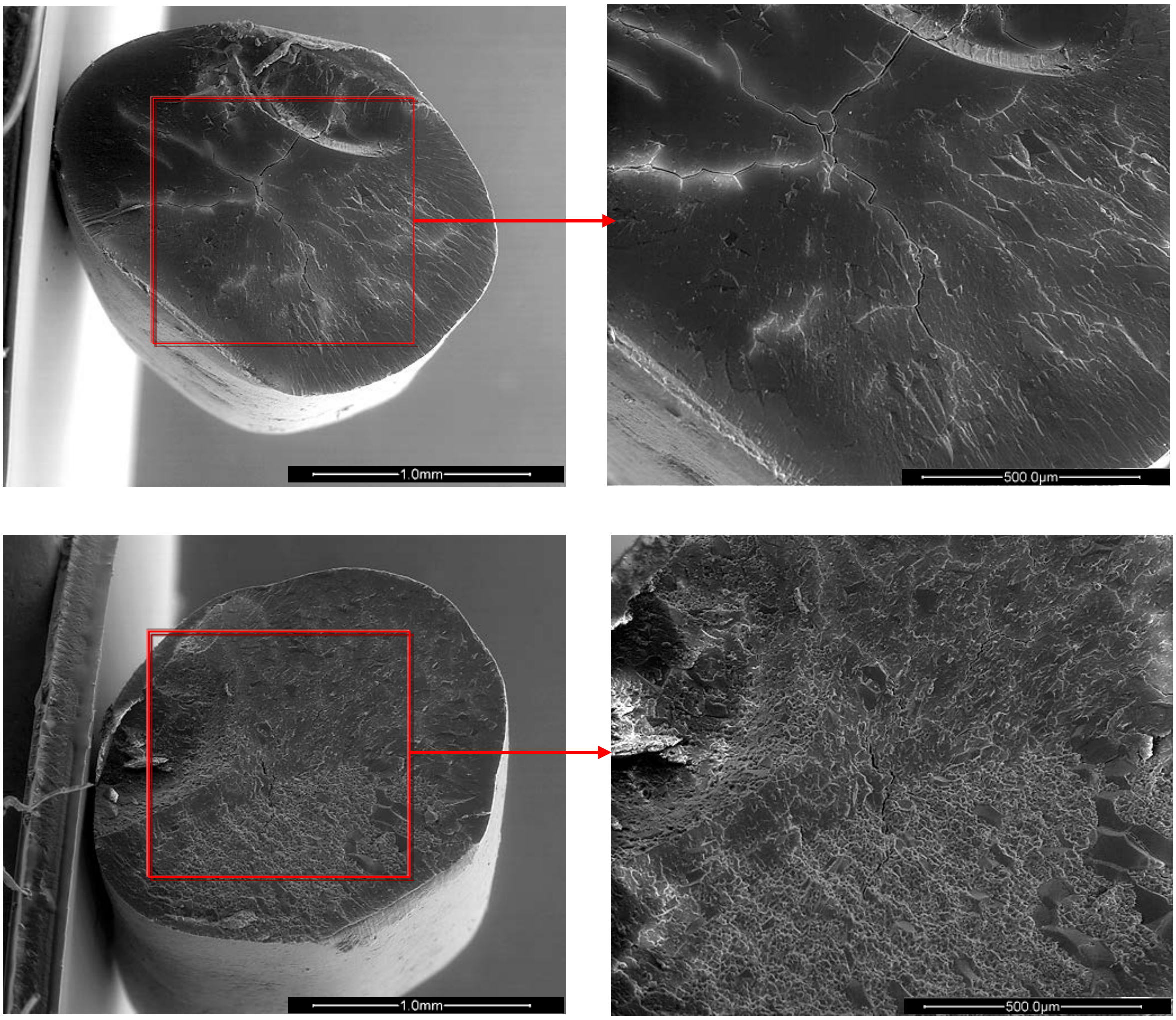

Figure 15. ESEM images of cross sections of uncooked Parboiled rice grains (left: 100x magnification, scale bar 1.0 mm; right: 200x magnification, scale bar 500 µm).

ESEM analysis was performed on uncooked Parboiled rice, production scale FD samples and COTS-A. The outer surface and cross-sections of freshly snapped grains were analysed. In the images presented here, the stated magnifications refer to ESEM settings, not the scale at which images appear on the page. Scale bars are provided in each image to enable an estimation of actual size.

The upper images show a smooth cut surface with clearly visible fine cracks or fissures within the grains. McFarlane et al. [15] and Ogawa et al. [16] also observed this type of cracking. The lower images show a fracture surface with smooth areas where the fractures occur between polygonal compound granules, and rough areas where the fractures break through compound granules revealing individual starch granules.

Control-C is Parboiled rice after cooking using the kettle method, followed by freeze drying using the production scale freeze dryer. Figure 16 shows Control-C as whole grains (16 A) and in cross section (16 B-D).

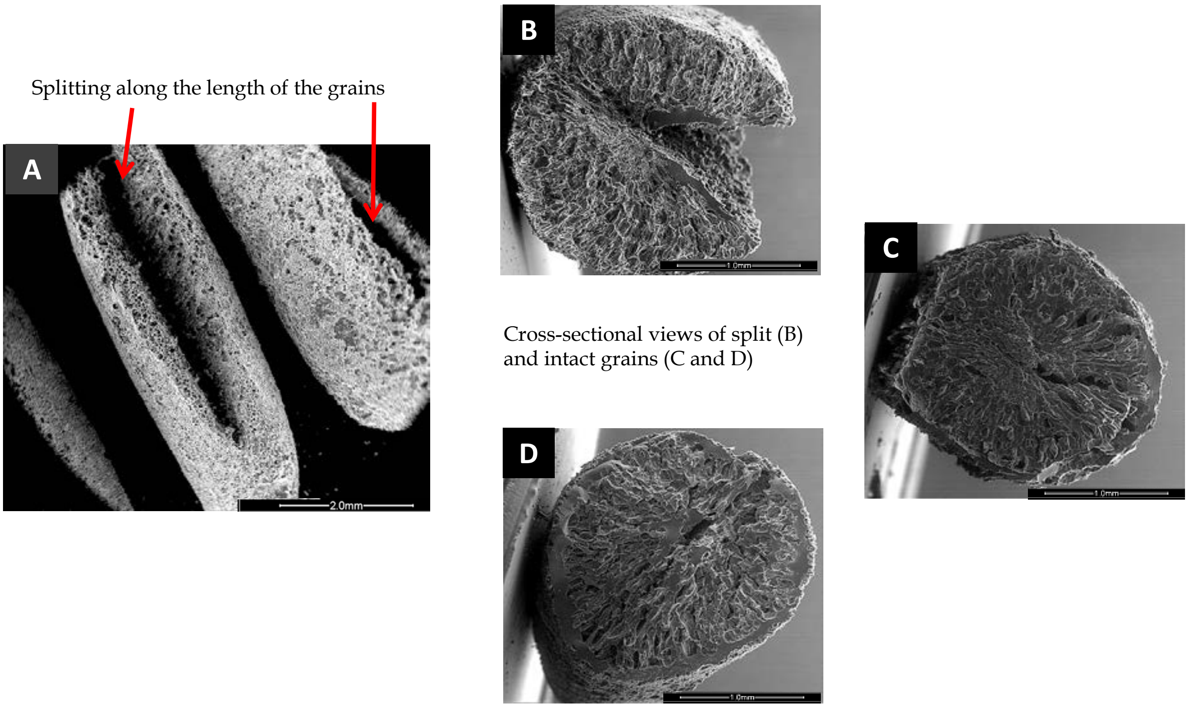

Figure 16. ESEM images of Control-C: whole grain (A, 40x magnification, scale bar 2.0 mm) and cross sections (B, C and D, 100x magnification, scale bar 1.0 mm)

The grain structure appears disrupted in comparison to the uncooked grains. Longitudinal splitting along the ventral crease of the grain, voids and large fissures were frequently observed. The cooking and freeze drying processes cause the grains to expand as water is absorbed and gelatinisation takes place, followed by further expansion and disruption when the rice is frozen, then evacuation of spaces as the ice is removed by freeze drying. This leaves behind voids and channels that can take up water again during rehydration.

Figure 17 shows images of Parboiled rice that was kettle cooked in the production facility and dried in the production scale freeze dryer (Control-C, top pair of images), and Parboiled rice that was kettle cooked (same cooking batch as Control-C) but dried in the laboratory freeze dryer (bottom pair of images).

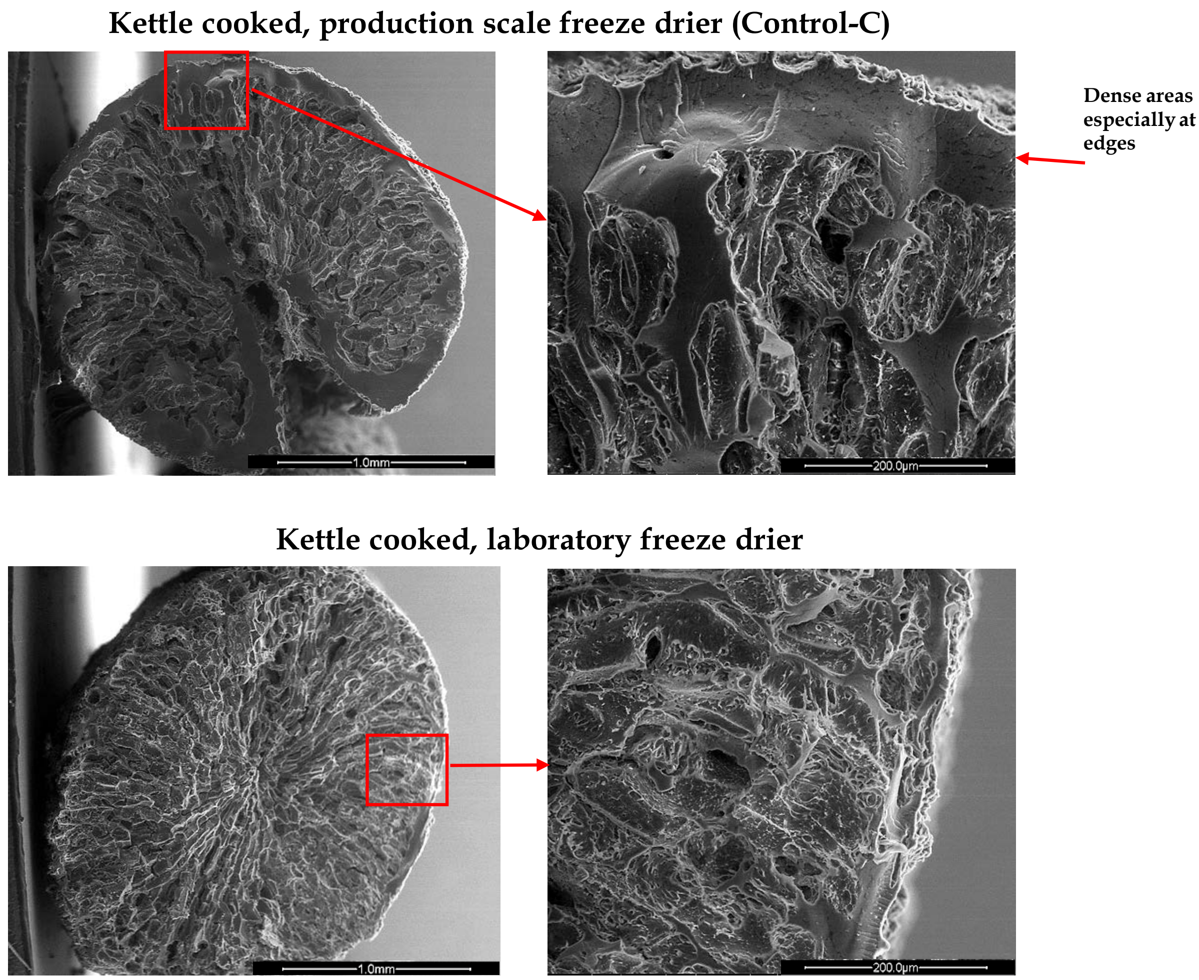

Figure 17. ESEM images of FD rice cross sections: Top images – sample was freeze dried using production scale freeze drier; Bottom images – sample was freeze dried using laboratory freeze drier. Left: 100x magnification, scale bar 1.0 mm, and right: 500x magnification, scale bar 200 µm.

The distinct difference is the presence, in the top pair of images, of 'case hardening' material that appears as smooth, dense regions mainly at or close to the surface of freeze dried grains, and in this example, along both sides of the split and into the centre of the grain. The case hardening may provide a degree of physical protection for the grain during handling, storage and distribution, but may also have negative impacts such as reducing rehydration rate, reducing completeness of rehydration and reducing textural quality. It is known to influence pore formation and may lead to surface or internal cracking [17].

Case hardening is commonly seen in foods that have been hot air dried, due to the initially rapid loss of moisture causing shrinkage and hardening of the outer layer of the food being dried [18]. Some examples of case hardening of grains dried in the laboratory scale freeze dryer were also observed, although to a lesser degree (Figure 18), as were examples of grains without case hardening following production scale freeze drying.

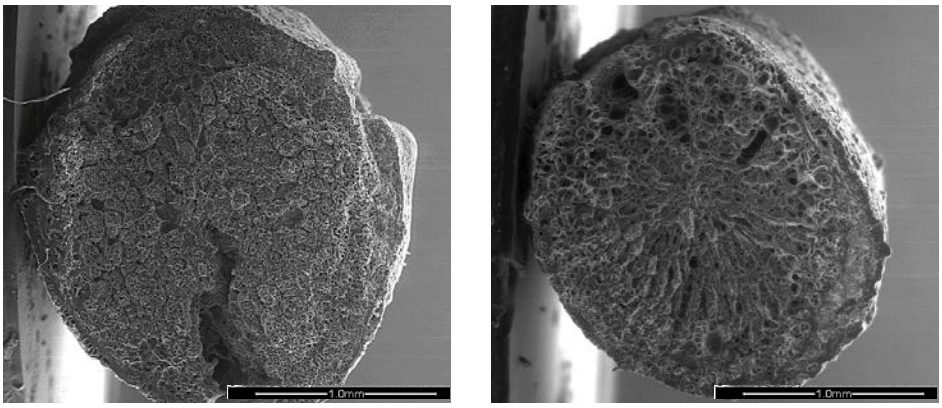

Figure 18. ESEM images of Jasmine (left) and Basmati (right) cross sections, using rice cooker and laboratory freeze drier; 100x magnification, scale bar 1.0 mm.

If the case hardening is due to an initially rapid loss of moisture, then this would be more likely in the production scale freeze dryer which operates under relatively harsh conditions compared to the laboratory freeze dryer (review section 3.2.2 for details). Location on the freeze dryer tray may also be important, as material in the vertical centre of the load would be protected from the full impact of the radiant heat from the platens (production scale freeze dryer).

The importance of case hardening as a determinant of FD rice quality should be determined, and subject to it being important, the role played by freeze drying conditions should be investigated.

ESEM images of the snap cross-sections of Jasmine, Basmati, Parboiled and Control-C are presented together so that the morphological structures of these rices can be compared (Figure 19). Jasmine and Basmati show intact oval to rounded profiles encasing fairly uniform starch structures with a few voids. Control-C grains are slightly more open and porous than Jasmine and Basmati, but the difference is marginal, although as observed elsewhere in this report, Control-C grains are prone to splitting at the ventral crease as can be seen in Figure 16B.

The Parboiled grains have less regular profiles with some splitting at the ventral crease, some larger voids and a generally more open and porous-looking structure. Parboiled grains are generally more open and have larger voids than Control-C, most probably due to the practice of undercooking Control-C. The higher swelling ratio of Parboiled rices results in the development of this open and porous structure as more water is absorbed relative to

non-Parboiled rices, and pores and voids are left behind as the ice is removed during freeze drying. Note the presence of case hardening in these images; all were freeze dried in the production scale freeze dryer.

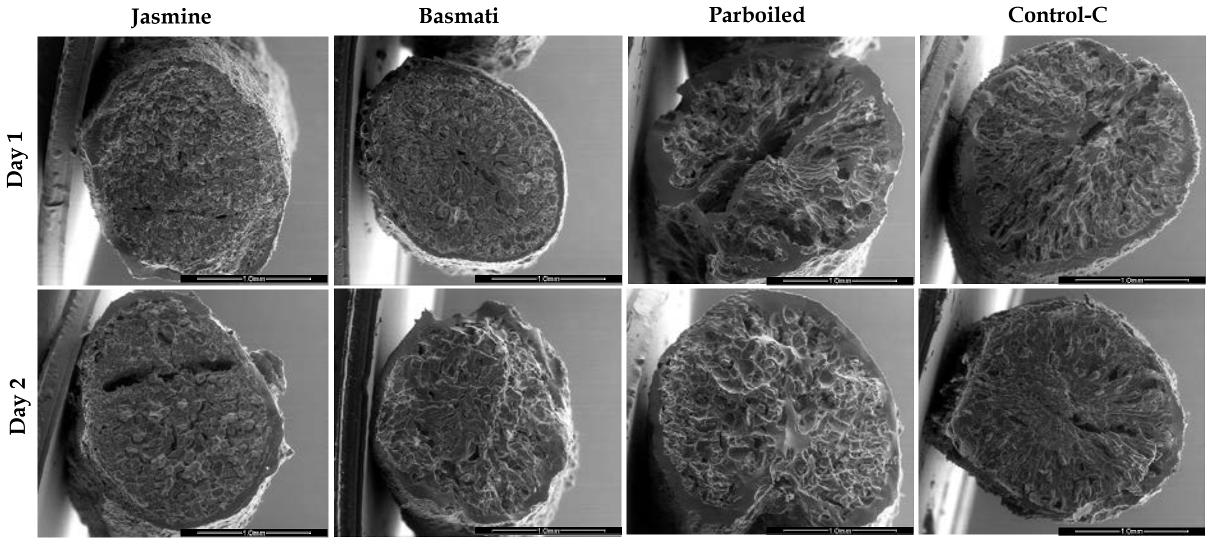

Figure 19. ESEM images of cross sections of production scale trial samples and Control-C (100x magnification, scale bar 1.0 mm)

From Figure 19 it can be seen that there is significant morphological variation, from grain to grain, within the same type of rice, processed under the same conditions. It is this type of variation that was noted in section 4.1.2 as a contributor to the level of uncertainty associated with the measurement of texture.

Control-C and COTS-A are functionally comparable, in the sense that both are simple, consumer-ready, freeze dried rice products. However, their morphological structures are very different (Figure 20). The external surface of Control-C appears porous, pitted and approximately uniform and regular in shape. The external surface of COTS-A appears distorted, misshapen, rough and relatively non-porous. The snap cross section of Control-C has been described above. Relative to Control-C, the snap cross section of COTS-A appears distorted, disrupted, more case hardened and has a few very large voids. Similarly, Prasert and Suwannaporn [18] found that instant rice grains had a hollow structure and were case hardened, and Dang and Copeland [19] observed quick cooking rice had a shrivelled appearance with a porous structure containing air pockets. The hollow structure of COTS-A may have contributed to the high breakage rate (estimated to be >80%), although it should be recognised that as a COTS item it has been subjected to the rigours of a commercial supply and distribution system.

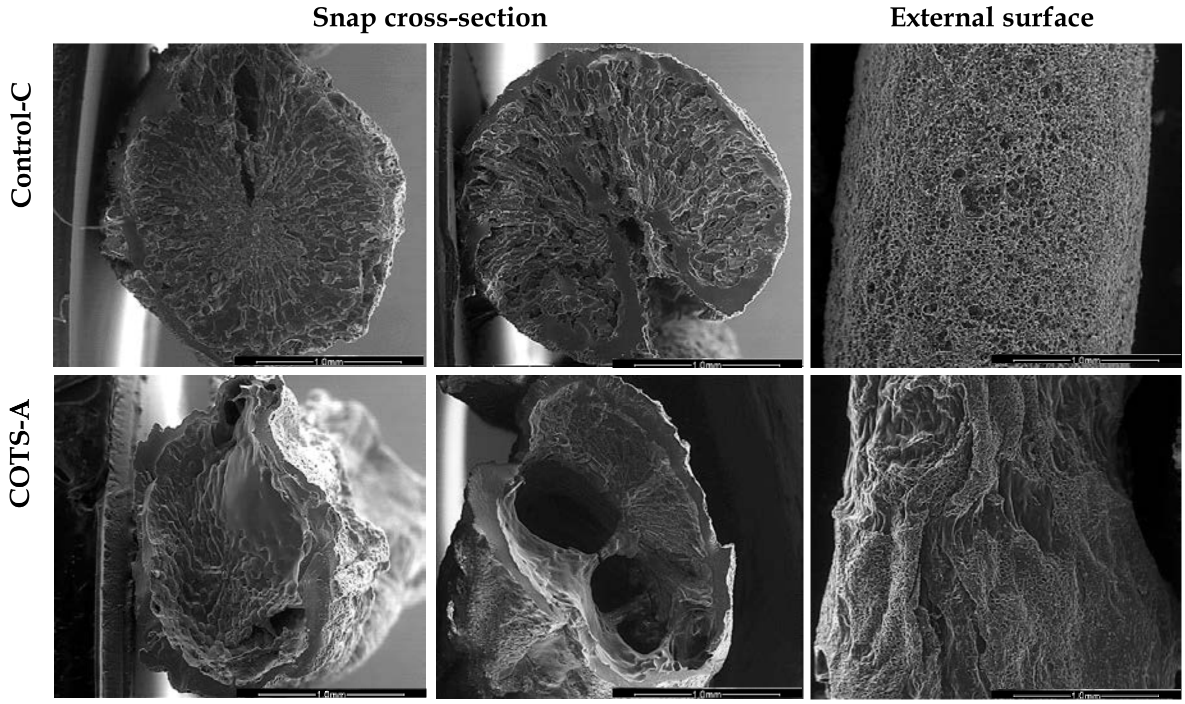

Figure 20. ESEM images of Control-C and COTS-A: cross sections and 'along the grain' (100x magnification, scale bar 1.0 mm)

5. Summary of Findings

Rice cooked using the rice cooker absorption method was superior in flavour, texture and physical integrity compared to rice cooked using the stove top, excess boiling water method. The rice cooker method gave more consistent results, possibly through allowing the starch to become fully and evenly gelatinised.

Jasmine and Basmati rices cooked by rice cooker were sticky and difficult to spread on freeze dryer trays, whereas Parboiled rice cooked by rice cooker was easily spread on the trays. The multiple washing steps employed in the production facility to rinse the kettle-cooked Parboiled rice may not be necessary to facilitate spreading on the freeze dryer trays. The difficulty in spreading Jasmine and Basmati rices would need to be addressed, otherwise the production scale freeze drying of Jasmine and Basmati rices cooked by rice cooker would be neither practical nor efficient.

There was evidence that cooking rice in excess boiling water, with frequent stirring and multiple washes, damages the rice and results in a very poor quality freeze dried product.

Sensory evaluations found rehydrated FD Jasmine, Basmati and Parboiled rices—cooked by rice cooker prior to freeze drying—were superior to rehydrated Control-A, Control-C and COTS-A rices. The most significant problems with the latter were bursting and breakage of grains and mushy, chalky, grainy textures with bland flavours. Grains of Parboiled rice were intact with no burst grains observed. Based on sensory evaluations and TPA, rehydrated FD rices were softer and less 'springy' than freshly cooked rices of the same types. Rehydrated

FD Parboiled rice was superior to the Jasmine and Basmati rices in terms of breakage of grains; of the three, Jasmine had the softest texture. Parboiled rice retained its integrity and appearance better than Jasmine and Basmati rices, although Basmati was less gritty than Parboiled and Jasmine.

The superior sensory quality of rehydrated FD Parboiled rice cooked by rice cooker compared to Control-C is due the different processing methods. The practice of undercooking Control-C may be a significant contributor to its lower quality.

Examination of ESEM images identified case hardening of FD rice grains, almost entirely confined to samples freeze dried using the production scale freeze dryer. The cause and importance of case hardening as a factor affecting quality is not clear, but should be investigated.

Based on ESEM images, FD Jasmine and Basmati rices had less porous structures than FD Parboiled and Control-C rices. The morphology of COTS-A rice was characterised by shrivelled, distorted grains, a case hardened exterior and an open porous structure containing large air pockets. The possibility of a link between this structure and sensory qualities when rehydrated should not be overlooked.

The findings of this study will provide guidance for Phase 2, in which an expanded series of production scale improvements will be conducted and evaluated.

6. Conclusions

It is concluded that:

- there is scope to refine in-house processing conditions to improve final product quality
- rice cooked by an absorption method and freeze dried is of better quality than rice cooked in excess boiling water prior to freeze drying
- sensory and physical characteristics of FD rice depend on the rice type, processing method and freeze drying conditions, although the precise relationships have not been determined.

ESEM imaging was found to be useful for examination of FD rices. It indicated that:

- case hardening of FD rice grains may be linked to freeze drying conditions
- internal structures of the rices are more open and porous following cooking and freeze drying, however there may be an upper limit to pore size beyond which quality is sacrificed.

An improved understanding of the relationships among processing conditions, structure, physical characteristics, rehydration behaviour and sensory quality would facilitate efforts to improve the quality of FD rice.

7. Recommendations

- Develop improved knowledge of the structure of FD rice and textural parameters to inform refinements to processing conditions:
    - in addition to the use of ESEM, investigate the suitability of small angle X-ray scattering and focussed ion beam scanning electron microscopy to examine internal structures
    - quantify porosity and density
    - investigate the cause and importance of case hardening as a factor affecting the quality of FD rice
    - investigate links between structure and breakage susceptibility, rehydration behaviour and sensory quality.
- Review current, in-house, rice cooking practices, including cooking time, frequency of stirring and number of rinses.
- Investigate at a production scale, the feasibility of cooking rice by an absorption method prior to freeze drying.

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Lan Bui and Ross Coad

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19. ABSTRACT
The focus of the work reported here is to evaluate a selection of readily available rices to determine cooking, freeze drying and rehydration characteristics, with the aim of improving the quality of freeze dried rice used in Australian military ration packs. Samples were examined by sensory evaluation, texture profile analysis and environmental scanning electron microscopy. The findings of this study will provide guidance for an expanded series of production scale improvements and evaluations.